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FLOOD PROTECTION IN INDIANA

BY

W. K. HATT
Professor of Civil Engineering
Purdue University

Indiana
Bureau of Legislative Information
Bulletin No. 4

December, 1914
INDIANAPOLIS

The Bulletins published by the Indiana Bureau of Legislative Information are:

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The Bulletins published by the Legislative Reference Department of the Indiana State Library (now the Indiana Bureau of Legislative Information) are:

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No. 5.	Digest of the Laws of Indiana of Special Application to Women and Children	1912
No. 6.	Inheritance Taxation	1912

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December, 1914

INDIANAPOLIS:
WM. B. BURFORD, CONTRACTOR FOR STATE PRINTING AND BINDING
1914

Indiana Bureau of Legislative Information

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INTRODUCTION.

Organized effort to study the causes and to lessen the effect of floods in Indiana began with the appointment of the Indiana flood commission by Governor Ralston on April 20, 1914.

This Commission is composed of one member from each congressional district and the personnel is as follows:

Mr. E. W. Shirk, Peru, Chairman.
Professor W. K. Hatt, Purdue University, Lafayette, Chief Engineer.
Mr. Frank C. Ball, Muncie.
Mayor Benjamin Bosse, Evansville.
Mr. William Cronin, Terre Haute.
Mr. Stephen B. Fleming, Ft. Wayne.
Mr. J. E. Frederick, Kokomo.
Mr. S. J. Gardner, New Albany.
Mr. Victor M. O'Shaughnessy, Lawrenceburg.
Mr. Joseph C. Schaf, Indianapolis.
Mr. W. N. Showers, Bloomington.
Dr. Chas. K. Stoltz, South Bend.
Mr. Herman Trichler, Brookville.

The Commission met first in Indianapolis, on April 30, 1914.

The purpose of this Commission is to consider the extent of damage due to floods in the State of Indiana, and to report to the Governor what measures should be taken to provide relief in the future.

The Commission expects to issue its detailed report early in 1915. This report will contain a full presentation of the history of floods in Indiana, a summary of the causes of floods, a collection of available data of rainfall, river discharge and topography, a discussion of flood protection works and a discussion of the principles of legislation to provide for flood relief.

This present pamphlet is an abstract of the forthcoming report of the Commission, prepared in non-technical style in order that citizens may inform themselves upon this very important subject.

JOHN A. LAPP.

FLOOD PROTECTION IN INDIANA.

FLOOD OF MARCH, 1913.

The appointment of the Indiana Flood commission was the direct result of the flood of March, 1913, in which 467 lives were lost and over $160,000,000.00 of property destroyed in the United States. The memory of this catastrophe is still fresh in the minds of the people of Indiana, in which State 39 lives were lost, and over $25,000,000.00 of property destroyed.

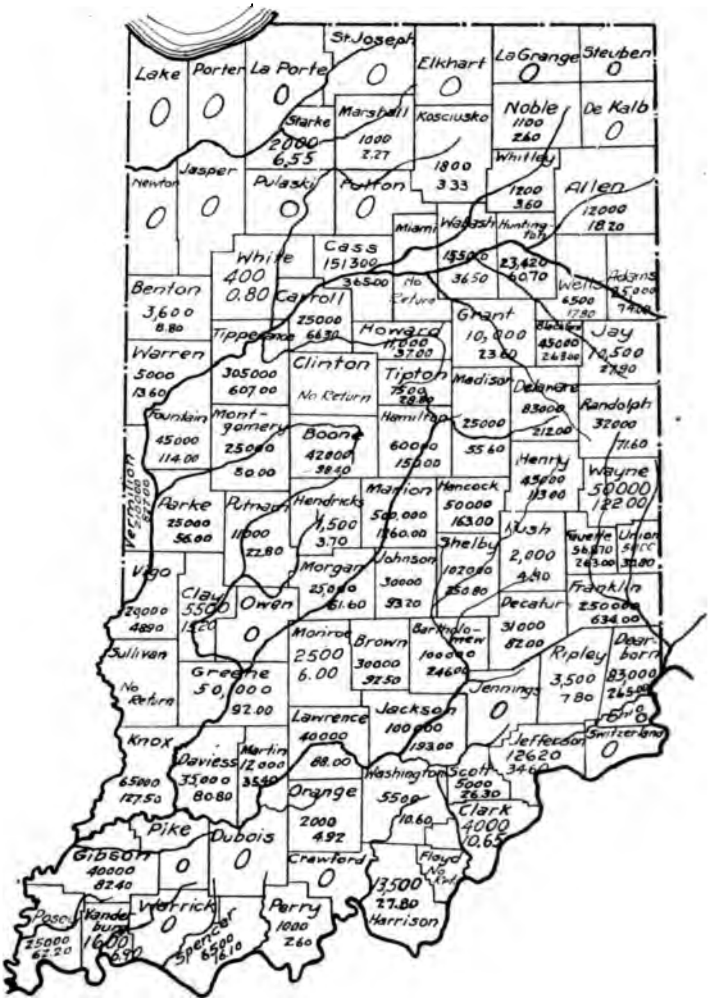
The total loss in the flood of March, 1913, can never be known. The interruption of transportation and of business, the destruction to farm lands by cutting of banks of rivers and covering of bottom lands with gravel, the loss of productive capacity of manufacturing plants, and the sickness following exposure, are not susceptible of exact computation.

Professor Beede of Indiana University reports a total damage of approximately one-half million dollars, in seven counties in the lower White River basin, in which also nearly eight thousand acres of agricultural land were denuded of soil and some sixteen thousand acres of river bottoms were covered with sand and silt. He estimates the loss to agricultural land in this region as nearly $250,000.00.

Part of the damage to country roads and bridges reported by the county auditors was over $3,000,000.00. (See Map 1.) Other tangible losses that have been determined are shown in Table 1. It is probable that other losses during the flood of March, 1913, in Indiana will bring the total losses to more than $25,000,000.00.

Indeed the catastrophe was so general over the Ohio Valley that it excited the sympathy and support of the entire nation. The Governor of the State of Indiana received $141,088.96 in subscriptions for the relief of flood sufferers in this State.

MAP No. 1.



MAP OF INDIANA, SHOWING PART OF DAMAGE TO HIGHWAYS AND HIGHWAY BRIDGES AS ESTIMATED. FLOOD OF MARCH, 1913.

NOTE. Upper figures, total loss; lower figures, loss per square mile.

TABLE No. 1.

PART OF DAMAGES SUSTAINED IN INDIANA IN THE FLOOD OF MARCH, 1913.

1.	County Highways and Bridges	$2,825,240 00
2.	Railroads—Steam	5,299,810 00
3.	Electric Railways	788,000 00
4.	Buildings and Personal Property	8,104,250 00
5.	Telephone and Telegraph	200,000 00
6.	Crops	735,700 00
7.	Live Stock	149,380 00
8.	Farm Lands (part of White river only)	247,500 00
9.	Suspension of Business	582,000 00
	Total	$18,949,390 00

Counties not included in (1)

Cass,
Floyd,
Clinton,
Miami,
Fayette,
Sullivan

Railroads not included in (2)

Central Indiana R R.
Chicago and Wabash R. R.
Cin. Ham. and Dayton R. R.
Toledo, Peoria and Wstn.R.R.
Toledo, St. L. and Wstn. R. R.

Electric lines not included in (3).

Marion and Bluffton Trac. Co.
Bluffton, Geneva and Celina Trac. Co.
Central Indiana Lighting Co.
Indianapolis Street Ry. Co.
Louisville and Southern Trac. Co.
Louisville and Northern Ry. and Light Co.
Vincennes Traction Co.
Washington Street Ry. Co.

(5) Includes Indianapolis Telephone Co. and Central Union Telephone Co.

Counties in Flood Districts not included in (4), (6), (7) and (9).

Adams,
Blackford,
Cass,
Clark,
Clay,
Clinton,
Fayette,
Floyd,
Fountain,
Franklin,
Gibson,
Grant,
Greene,
Harrison,
Howard,
Huntington,
Jay,
Jefferson,
Ohio,
Parke,

Perry,
Putnam,
Randolph,
Ripley,
Scott,
Sullivan,
Switzerland,
Tippecanoe,
Vanderburgh,
Vermillion,
Vigo,
Wabash,
Warrick,
Wells,
White,
Whitley.

(8) Includes loss only in 230 miles of East and West Forks of the White River through Morgan, Owen, Greene, Daviess, Knox, Jackson, Lawrence and Martin Counties.

FORMER FLOODS IN INDIANA.

Floods have occurred in Indiana as far back as records are obtainable. In the early days, before levees had been raised above high water, and before cities had been built in the bottoms, the losses were small, and people did not have to pass over the river until the flood waters subsided.

In recent years the effects of similar floods have become more serious, and the problem has become acute. It has been made so by the inevitable encroachments on the flood plains and bottoms which were formerly given up to the rivers during floods, while at the same time, channels have not been improved in proportion to the encroachment.

The Indianapolis News of September 26, 1914, contains a summary of the report on historic floods in Indiana prepared by the State Librarian, Mr. Demarchus Brown. Mr. Brown's report is of great interest and value, and is summarized for Indiana in Table 2.

This Table shows only severe and widespread floods that occurred in this State. It is seen that the average interval between Indiana floods of great magnitude is six and one-fourth years. The numerical values at Ohio River points indicate the height of the gauge above danger point. The floods on the Ohio River which damaged such cities as Louisville, Jeffersonville, and Evansville, are also included under "Ohio River."

A quotation from the "Lawrenceburg flood report, 1913", will instance the situation in one locality,—

"The records of the Weather bureau show that not a single year of the forty immediately preceding 1913 has

TABLE No. 2—Showing the periodicity of great floods in the Ohio River valley.

	PITTSBURGH F.S. 22.0	WHEELING F.S. 36.0	PARKERSBURG F.S. 36.0	MARIETTA F.S. 35.0	CINCINNATI F.S. 50.0	LOUISVILLE F.S. 28.0	EVANSVILLE F.S. 35.0	PADUCAH F.S. 43.0	CAIRO F.S.	WABASH	E.FK WHITE	W.FK WHITE	WHITEWATER	OHIO	MIAMI	SCIOTO
1773					Tradition 28										Mar (Trad'n)	
1789														May Sept		
1805															Jan'y	
1806	Apr 11.9															
1810	Nov 10.0													Dec		
1813	Jan 7.0													Jan		
1815														Spring		
1816	Feb 11.0															
1824														Mar		
1828															Feb'y	
1832	Feb 13.0		Feb 13.5		Feb 14.3	Feb 17.8	Feb 11.3							Feb'y	Feb'y	
1840																
1846														Mar		
1847					Dec 13.6					Jan'y	Jan'y	Jan'y	Jan'y		Jan'y	
1851	Sept 8.9															
1852	Apr 9.9															
1857										June						
1858											Apr	Apr		Apr		
1859					Feb 9.3											
1860	Apr 7.7															
1861	Sept 9.0															
1862	Jan 8.0				Jan 7.3											
1863	Apr 5.9															
1865	Mar 9.4				Mar 6.4											Sept
1866										Sept	Sept	Sept	Sept	Sept	Sept	
1867					Mar 5.8			Mar 9.0								
1870					Jan 5.3											Jan
1873																
1874								Apr 3.7								
1875							Aug 6.9			Aug				Aug		
1876							Jan 8.3									

Note: The decimal points have not been reproduced in all cases in this cut.

	PITTSBURGH	WHEELING	PARKERSBURG	MARIETTA	CINCINNATI	LOUISVILLE	EVANSVILLE	PADUCAH	CAIRO	WABASH	E FK WHITE	W FK WHITE	WHITEWATER	OHIO	MIAMI	SCIOTO
1877							Jan 6.5									
1881	June 51															
1882					Feb 86	Feb 94	Jan 59 Feb 99	Jan 58 Feb 7.0	Feb 69					Feb		
1883	Feb 60		Feb 92	Feb 8.1	Feb 163	Feb 16.4	Feb 128	Feb 77	Feb 7.2	Feb				Feb	Feb	Feb
1884	Feb 113	Feb 121	Feb 178	Feb 178	Feb 211	Feb 18.5	Feb 138	Feb 11.2	Feb 6.8	Feb				Feb		
1886					Apr 58		Apr 84	Apr 74								
1887					Feb 63		Feb 87 Mar 81									
1890					Mar 68	Mar 6.1	Mar 89	Mar 55								
1890					Mar 92	Mar 7.5	Mar 94									
1891	Feb 93	Feb 89	Feb 86	Feb 88	Feb 73		Mar 78									
1893							Mar 68 May 53									
1897	Feb 75				Feb 11.2	Feb 7.4	Mar 86	Feb 79	Mar 6.6	Mar	Mar	Mar	Mar		Mar	
1898	Mar 79	Mar 82	Mar 11.8	Mar 125	Mar 114	Mar 83	Jan 81 Apr 98								Mar	Mar
1899					Mar 7.4		Mch 77 Apr 54									
1900	Nov 67															
1901	Apr 55			Apr 6.4	Apr 97		Apr 68									
1902	Mar 104	Mar 64					Mar 50									
1903							Dec 50									
1903	Mar 69						Feb 57 Mar 74		Mar 5.6							
1904	Jan 80	Jan 79		Jan 58						Mar	Mar	Mar	Mar	Mar		
1905	Mar 70	Mar 63	Mar 6.4	Mar 54												
1906							Apr 61									
1907	Mar 155	Mar 141	Mar 156	Mar 137	Jan 152 Mar 121	Jan 134 Mar 80	Jan 112 Mar 88		Jan 54	Jan	Jan		Jan	Jan		
1908	Feb 87 Mar 53	Feb 64	Feb 52		Ap 59		Feb 59 Mar 65 Apr 72			Mar May	May	Mar May		May		
1909						Feb 50	Mar 8.2									
1910										Oct	Oct	Oct	Oct	Oct		
1912	Mar 61						Mar 76	Apr 69	Apr 9.0							
1913	Jan 93 Mar 84	Jan 82 Mar 151	Jan 91 Mar 233	Jan 76 Mar 198	Jan 172 Mar. 208	Jan 115 Mar 163	Jan 117 Mar 133	Jan Mar 113	Mar 98	Jan Mar	Jan Mar	Jan Mar	Jan Mar	Jan Mar	Jan Mar	Jan Mar
	From Weather Bureau ~ Bull. Z										From Newspaper					
	and U.S.G.S.~W.S. Paper-334										Accounts					

been free from devastating floods in some part of the Ohio Valley. * * * The historic floods in the Cincinnati district and the territory contiguous thereto were in the years 1773, 1832, 1847, 1883, 1884, 1897, 1898, 1907, and 1913. In every one of these floods the crest of the rise exceeded sixty feet on the Cincinnati gauge. The danger line at Cincinnati is fixed at fifty feet. Thirty-five times since 1832 has the water at Cincinnati passed the fifty-foot mark. Seventy-seven times since 1832 has it passed the danger line at Pittsburg, twenty-eight times at Wheeling, twenty-five times at Marietta since 1873, eighty-six times at Evansville, and twenty-eight times at Paducah. There is, therefore, a constant menace to life and property along the Ohio River and its tributaries. * * * In this danger zone Lawrenceburg, Indiana, is peculiarly situated. * * * The mean level of the city, therefore, is approximately eleven feet below the crest of the highest flood of which we have definite knowledge, and ten feet below that of April, 1913. Perhaps four-fifths of the city lies below the line of sixty feet and, consequently, would have been flooded no fewer than a dozen times in the last half century had there been no artificial barrier. Four times within thirty-two years has the artificial barrier been swept away and the city completely inundated. These unfortunate occurrences were in 1882, 1883, 1884, and 1913."

Cities like Indianapolis, Fort Wayne, Peru, Logansport and Brookville are also in peril from future floods.

CHARACTERISTICS OF FLOODS.

Table 2 shows that serious floods may occur at any time throughout the year, but they usually happen between December and April. January, February, and March are the months when the combination of rainfall and surface conditions produce the worst effects.

Characteristics of Storms Preceding Floods.

January 1847—Rainfall.
June 1857—
September 1866—Series of heavy thunderstorms.
August 1875—Heavy rains following wet summer.
February 1883—High monthly precipitation with thaw.
March 1897—Series of excessive rains.

March 1904—Series of storms.
February 1908—Moderate rain with thaw.
October 1910—Single protracted storm.
January 1913—Single protracted storm.
March 1913—Two protracted storms, practically one.

A heavy storm, shedding long continued rain, sweeps up the Ohio Valley, and finds the ground frozen or covered with snow, the subsoil saturated and the channels already charged with water, so that the greater part of this rainfall runs off through the streams.

The tributaries may all be discharging and attempting to find outlet at the same time, through the main channel, in which people have been dumping refuse, constructing levees and buildings that add to the height of flood waters.

The meteorological conditions attending serious floods are made clear in Diagrams 1 to 4. A storm starts in the southwest and follows up a trough of low pressure between two high pressure areas on either side of the Ohio Valley. Sometimes a second storm follows up the first immediately, and it is a further burden upon the overtaxed channels. (See Diagram 1.)

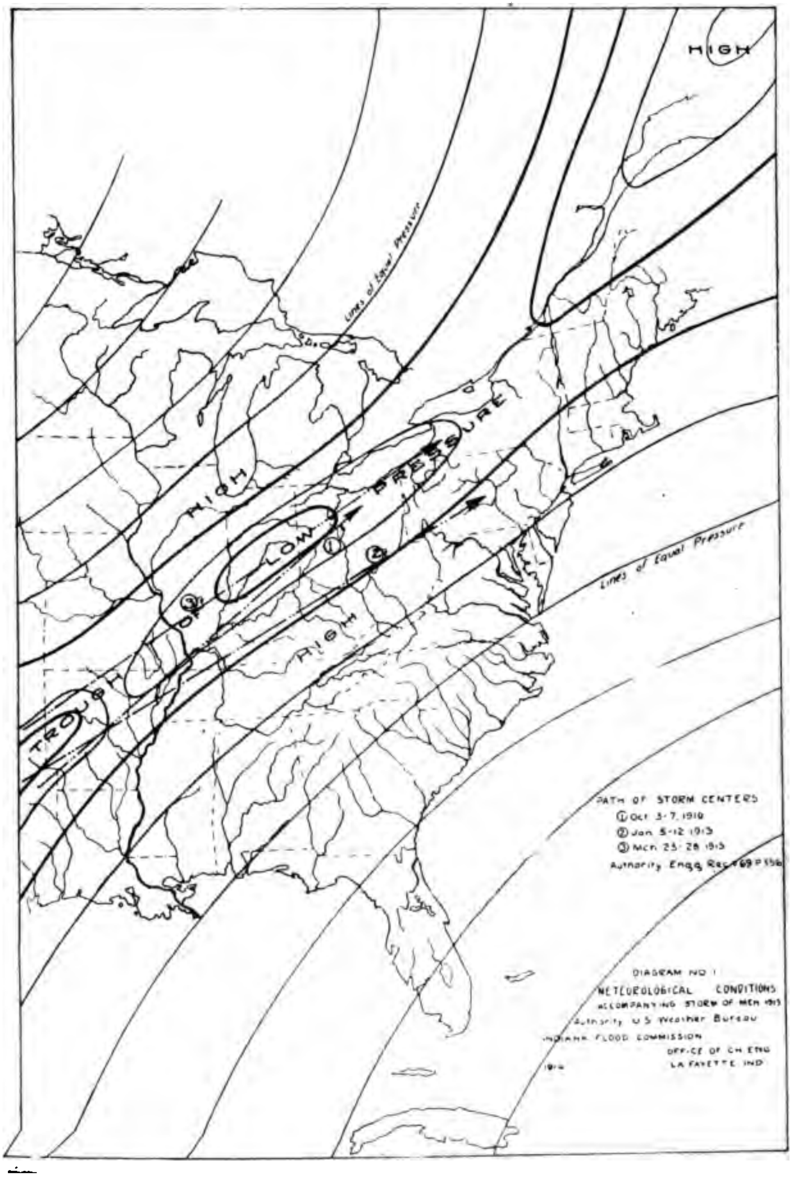
Records are available of three notable past storms. (shown in Diagrams 2 to 4) that of October, 1910; that of January, 1913; and that of March, 1913; characterized by a heavy intensity of rainfall over large areas, the two latter coming at the time of year when very little of the rainfall was absorbed in the ground.

As we shall see later, storms such as these are a measure of the amount of river discharge that flood protecton works must carry.

Diagram 1 shows the paths taken by these three excessive storms. The northern portions of Indiana lie outside the track of these storms. For example, the Eel River and the Tippecanoe River are not likely to receive as heavy rainfall as the East and West Forks of the White River, because the latter lie in the path of these severe storms.

Diagrams 5 and 6 are drawn to show the inches of rain-

DIAGRAM No. 1.


HIGH
Lines of Equal Pressure
HIGH
TROUGH OF LOW PRESSURE
LOW
①
②
③
HIGH
Lines of Equal Pressure
PATH OF STORM CENTERS
① Oct 3-7, 1910
② Jan 5-12 1913
③ Mch 23-28 1913
Authority Engg Rec #69 P 356
DIAGRAM NO 1
METEOROLOGICAL CONDITIONS
ACCOMPANYING STORM OF MCH 1913
Authority U S Weather Bureau
INDIANA FLOOD COMMISSION
OFFICE OF CH ENG
LA FAYETTE IND
1914

fall that fell at various localities affected by the storm. It is plain that large areas receive a less average rainfall than small areas. For instance, in Diagram 5, we find that in January, 1913, an area of 500 square miles had a rainfall in excess of eleven inches; an area of 2,500 square miles had a rainfall in excess of ten inches; and an area of 14,500 square miles had a rainfall in excess of eight inches. From a study of the three storms, Diagram 7 has been prepared to show the relation between an area of given size in a watershed, that lies in the path of these storms, and the amount of rain that may reasonably be expected on this area.

POSSIBLE FUTURE STORMS.

The storm of March, 1913, was not as heavy as either that of January, 1913, or that of October, 1910. Of course a combination of the storm of January and a snow-covered surface is possible, and would have caused a flood greatly in excess of that of March. It is fortunate that these storms sweep up, instead of down, the Ohio Valley, because the latter storm would tax the channel more severely than the former.

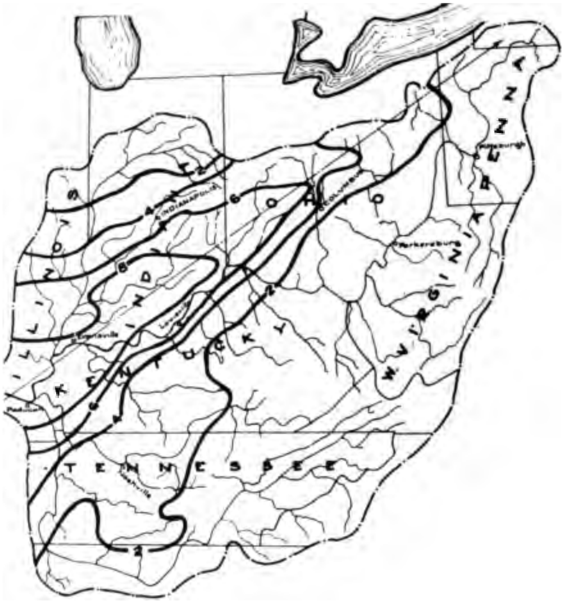
Of course, small areas in any part of the State may receive a heavy local rainfall, at any time of the year, and bridge openings must provide for this rainfall. For instance, in the Muskingum Valley an unprecedented rainstorm occurred in July, 1913, following the flood of March, 1913, causing flood heights higher than those of the previous storms. At one station a rainfall of 7.17 inches was recorded for a period less than nine hours.

But we are now speaking of storms that cause widespread floods over an entire watershed, and trying to estimate what rainfall we should provide for in improved channels and under bridges in plans for flood protection works.

A simple method is to specify that these works shall carry the rainfall of March, 1913, that caused the greatest flood on record, and then add to this an arbitrary increase of one-third in the White River and a less amount in the more northerly watersheds further removed from the path of extraordinary storms.

Diagram 6 shows (Lines a) the actual rainfall that occurred in the Wabash Valley and the two forks of the White River in March, 1913, and also (Lines b) the rainfall that would have fallen if the March storm had been increased by a factor of one-third on the White River, and a factor of one-fourth on the Wabash River. This increased rainfall on the East Fork of the White River and

DIAGRAM No. 2.

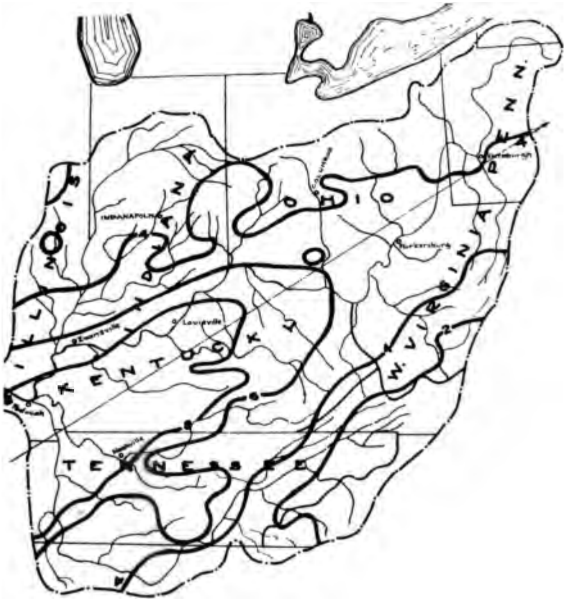


OHIO RIVER WATERSHED.
Total Precipitation October 3-6, 1910.

the lower Wabash River is nearly the same as that which would have occurred if the storm of January, 1913, had followed a path 75 miles farther north.

Of course if such a storm as that of October, 1910, were arbitrarily shifted to a path over the headwaters of the Wabash, extraordinary conditions would be found. As a matter of fact, however, the centers of these storms causing severe floods in Indiana do not pass this far north. It would be unreasonable to predict a rainfall intensity in northern Indiana and impose a factor of safety against future contingencies, as high as equal areas receive in the White River Valley.

DIAGRAM No. 3.

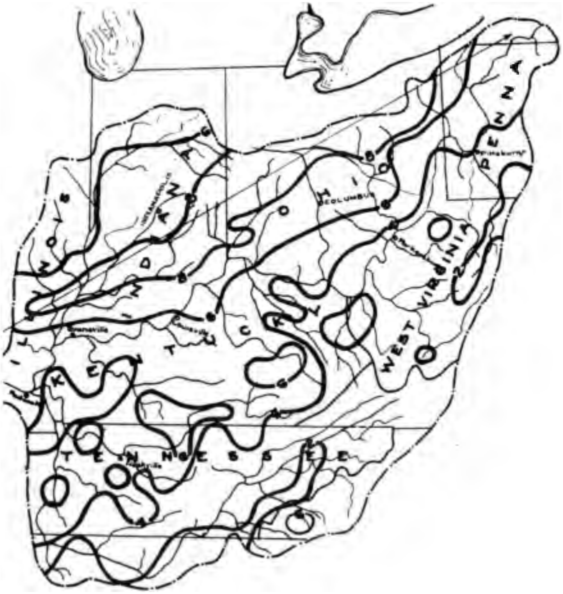


OHIO RIVER WATERSHED
TOTAL PRECIPITATION JANUARY 1-13, 1913.

CONCLUSION AS TO RAINFALL.

In general then, we may reasonably require that the constructions for flood protection works on the Wabash and the White Rivers should provide for the rainfall shown by the lines in Diagram 7.

DIAGRAM No. 4.



OHIO RIVER WATERSHED.
TOTAL PRECIPITATION MARCH 23-27, 1913.

PERIODICITY OF RAINFALL.

A curious relation between the amounts of rainfall through cycles of years is evident from Diagram 8 which shows the distribution of yearly rainfall since 1830. The

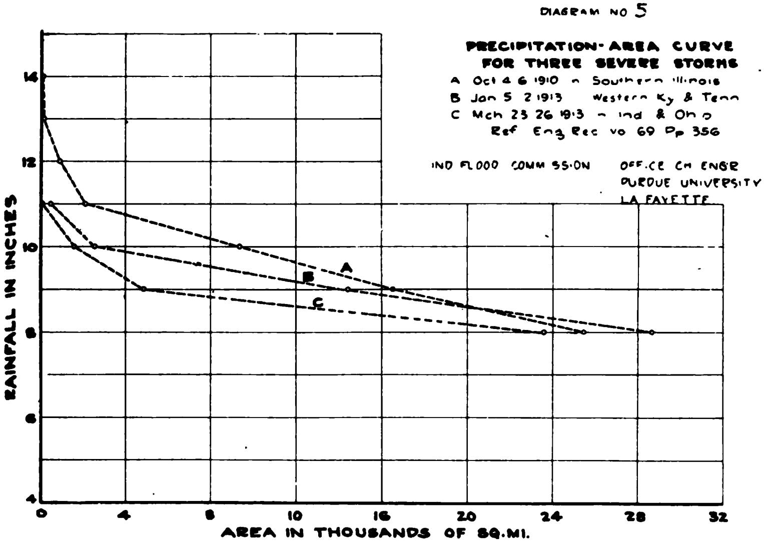


DIAGRAM NO 5

PRECIPITATION-AREA CURVE
FOR THREE SEVERE STORMS
A Oct 4 6 1910 in Southern Illinois
B Jan 5 2 1913 Western Ky & Tenn
C Mch 23 26 1913 in Ind & Ohio
Ref Eng Rec vol 69 pp 356

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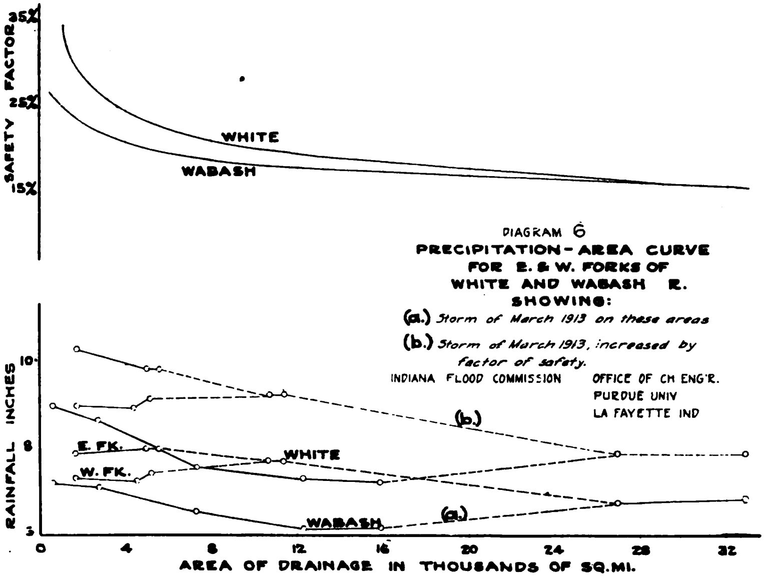

DIAGRAM 6

PRECIPITATION-AREA CURVE
FOR E. & W. FORKS OF
WHITE AND WABASH R.
SHOWING:
(a.) *Storm of March 1913 on these areas*
(b.) *Storm of March 1913, increased by factor of safety.*

INDIANA FLOOD COMMISSION

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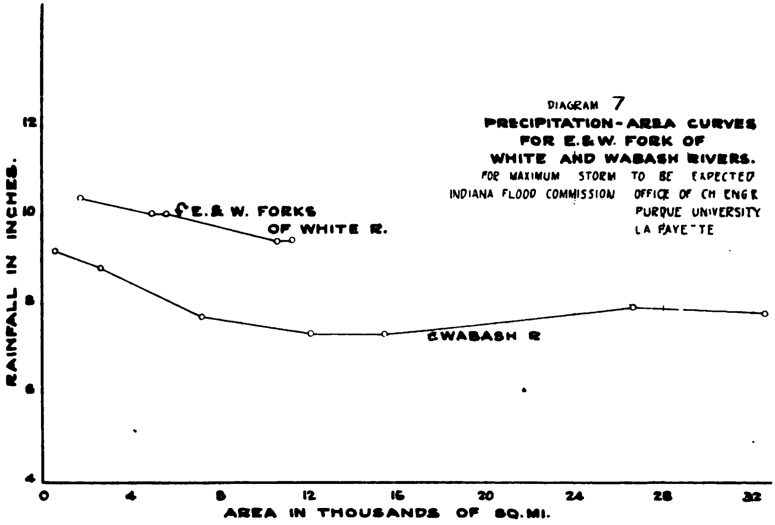
cycle of 34 years from a period of excessive rainfall to deficient rainfall is evident in the region around Cincinnati. On the basis of this Diagram, some are inclined to predict heavy floods in the near future. They say that we have been passing through a series of years of deficient rainfall in conjunction with increased farm drainage and growing encroachments upon stream channels, and that excessive floods are indicated for the near future.

DIAGRAM No. 7.



Inasmuch as the great floods occur in the months of January to March, inclusive, similar periodicity Diagrams have been drawn for these months, (See Diagram 9) and the close connection between the excessive rainfall and severe floods is evident.

These Diagrams (8 and 9) show progressive averages, that is to say, to obtain the rainfall for any year, the rainfall of the previous year and succeeding year are averaged along with the rainfall of the year in question. The latter is given double the weight of the others in this average.

RAINFALL AND STREAM DISCHARGE.

How much of this rainfall will discharge in the rivers? Only a part of the rain that falls on the upper reaches of a watershed ordinarily runs by a city below. Great floods occur when the greater part of the rainfall runs off in the streams during the extraordinary storms.

Part of the rainfall is held back for a time in porous subsoil, in swamps, and in the ground surface, especially in forest cover, and is let out gradually.

Part of the water also disappears through evaporation and is used by vegetation.

For instance, in the former days before land was drained for agriculture, the heavy rains of the winter and spring were held back in the swamps and other natural detaining agencies, until near mid-summer.

> "In the early days our country farmers in the down-stream part of the valley, as well as the up-stream part, plowed just the land which was readily tillable without artificial aid. Then, as population increased, land which needed artificial aid for cultivation was occupied. In the northern part of Illinois, where I was born and raised, I can remember distinctly the number of small swamps, the number of little pockets in cultivated fields where the water used to lie into the middle of the summer. But year after year our farmers have been putting down tile drains. They formed drainage districts and have cut ditches until now nearly the entire northeastern part of Illinois is drained dry almost immediately after a rainstorm in warm weather, or as soon as the snow is melted after the winter. The result is recognized even in our larger streams like the Des Plaines River and the Fox River. In the early days they tell us the water power from those streams was nearly permanent the year round. Now the water power has practically disappeared. We have high water for a month or two, and then historical remnants of the stream for the summer. These swamps used to act as regulators. The

DIAGRAM No. 8.

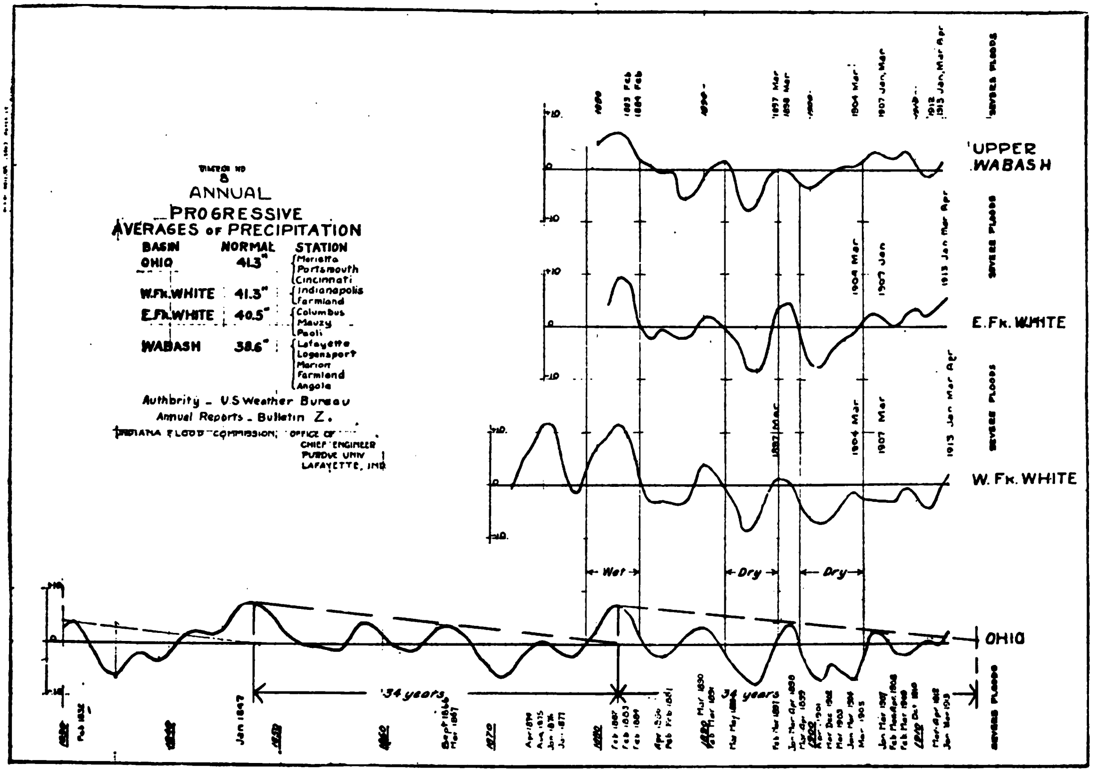


DIAGRAM NO
8
ANNUAL
PROGRESSIVE
AVERAGES OF PRECIPITATION
BASIN NORMAL STATION
OHIO 41.3" Marietta, Portsmouth, Cincinnati
W.FK.WHITE 41.3" Indianapolis, Farmland
E.FK.WHITE 40.5" Columbus, Mauzy, Paoli
WABASH 38.6" Lafayette, Logansport, Marion, Farmland, Angola
Authority - U.S. Weather Bureau
Annual Reports - Bulletin Z.
INDIANA FLOOD COMMISSION; OFFICE OF CHIEF ENGINEER PURDUE UNIV LAFAYETTE, IND
UPPER WABASH
E.FK. WHITE
W. FK. WHITE
OHIO
SEVERE FLOODS
+10
0
-10
1883 Feb
1884 Feb
1897 Mar
1898 Mar
1904 Mar
1907 Jan, Mar
1912
1913 Jan, Mar Apr
1904 Mar
1907 Jan
1913 Jan Mar Apr
1897 Mar
1904 Mar
1907 Mar
1913 Jan Mar Apr
Wet
Dry
Dry
34 years
34 years
Feb 1832
Jan 1847
Sept 1866
Mar 1867
1870
Apr 1874
Aug 1875
Jan 1876
Jan 1877
Feb 1882
Feb 1883
Feb 1884
Apr 1886
Feb Feb 1887
Mar 1890
Feb Mar 1891
Mar May 1893
Feb Mar 1897
Jan Mar Apr 1898
Mar Apr 1899
1900
Apr 1901
Mar Dec 1902
Mar 1903
Jan Mar 1904
Mar 1905
Jan Mar 1907
Feb Mar Apr 1908
Feb Mar 1909
1910 Dec 1910
Mar Apr 1912
Jan Mar 1913

DIAGRAM No. 9.

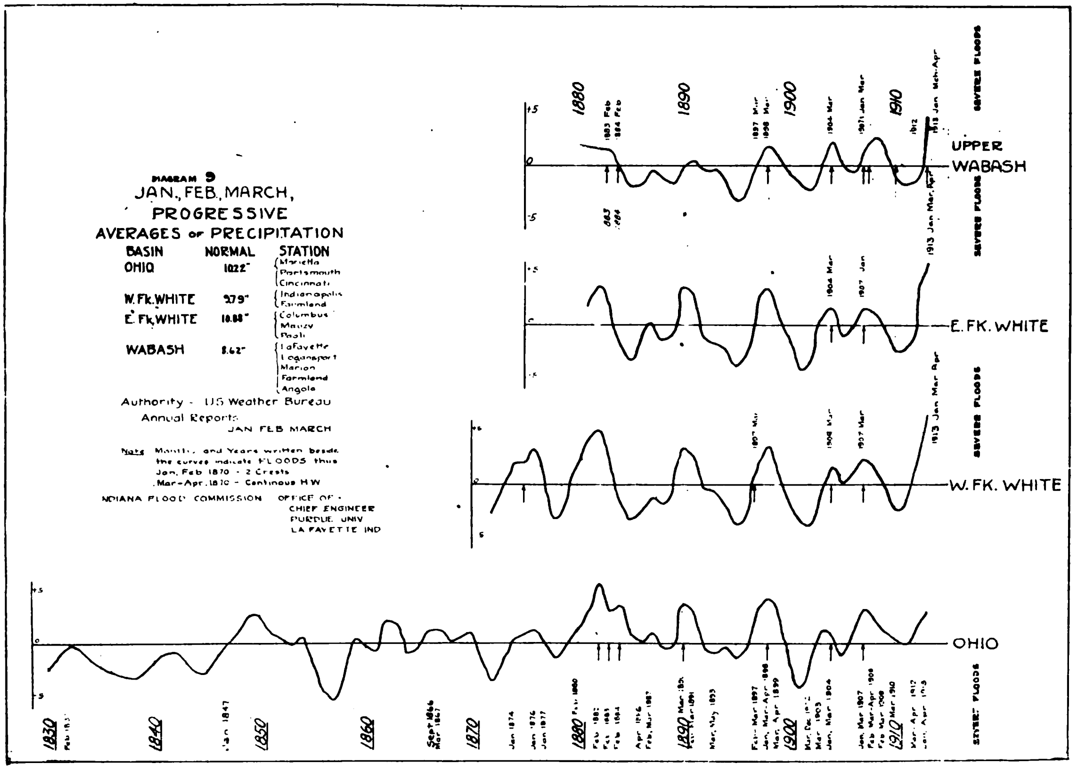


DIAGRAM 9
JAN., FEB., MARCH,
PROGRESSIVE
AVERAGES OF PRECIPITATION

BASIN	NORMAL	STATION
OHIO	10.22"	Marietta Portsmouth Cincinnati
W. Fk. WHITE	9.79"	Indianapolis Farmland
E. Fk. WHITE	10.88"	Columbus Mauzy Paoli
WABASH	8.62"	LaFayette Logansport Marion Farmland Angola

Authority - U.S. Weather Bureau
Annual Reports
JAN FEB MARCH

Note Months and Years written beside the curves indicate FLOODS thus
Jan, Feb 1870 - 2 Crests
Mar-Apr. 1870 - Continous H.W.

INDIANA FLOOD COMMISSION
OFFICE OF -
CHIEF ENGINEER
PURDUE UNIV
LA FAYETTE IND

high water of the spring would go into these bottom lands which were more or less in the form of rice marshes and fill them up with a raise of ten or twelve feet, and then as the river sank these bottom lands would discharge and help regulate the flow during the summer. Enterprising men have bought these lands and have put levees across on the river side with pumping machinery to pump out the water which fills in there, and they no longer serve to regulate the stream."—Robert McCormick in Bulletin No. 8, Rivers and Lakes Commission, State of Illinois.

There was then higher water in the streams throughout the summer than at present, and the ordinary workings of the river were more even.

There is no doubt but that, because of the cutting down of the forests and the draining of the swamps, and the construction of large drainage systems for farm lands, the rain now runs more rapidly to the watercourses, and the height between ordinary high and low water is greater. These new conditions must cause more frequent floodings of our river bottoms.

But these tremendous floods like March, 1913, are due to severe storms that send rain down upon the surface when the soil is already as full as a wet sponge, or frozen, or when there is snow on the ground. Even if the swamps and forests were in existence, they would have had no further capacity left to take this heavy rainfall. It would have run quickly into the streams as it does now.

Then too, in early times, the bottoms of the rivers were grown up in thick forests which offered great resistance to the free flow of flood waters over the bottoms outside of the river channel.

"The character of the Valley Lands of the Illinois River, as described in official reports, is shown by the following excerpts: Howard Stansbury, 1838—(U. S. Topographical Engineer) 'The bottom lands extend from one to five miles on each side of the river, seldom rising more than a few feet above the level of the stream in its ordinary stages, and from the fact that they are constantly overflowed, by every freshet, to a depth varying from one to fifteen feet, are now and must ever remain uninhabited.

Hence the river presents the appearance of flowing through an ancient, vast and solitary forest, clothed with a foliage rich and luxuriant beyond description, where solemn silence has never been broken, save by the howl of the panther, or the still more savage yell of the redman.' "—Quoted in "The Illinois River, Physical Relations and the Removal of the Navigation Dams." The Sanitary District of Chicago.—By Lyman E. Cooley.

Those who have given close study to the matter are not able to find evidence that the flood heights during these extreme floods are higher than flood heights in early days, except in the cities and other localities where the embankments, levees, buildings and bridges have made local obstructions that dam up the waters, and create a head of back water.

One serious problem in Indiana at present is the control of future obstructions to the free flow of flood water in our streams, and to remove present obstructions that will interfere with the building of flood protection works by our cities.

DETERMINATION OF RIVER DISCHARGE.

The part of the rainfall that runs off into the streams, that is, the "runoff", is expressed as river discharge. The shape of the watershed whether long and narrow, or short and wide, and the character of the surface, whether rocky or with deep gravel sub-soil, and the convergence of the side tributaries and the steepness of the watershed, each has its own particular effect on the rate at which the runoff reaches the river channel.

A long narrow watershed will not deliver rainfall as quickly to a point in the channel below as will a short and compact watershed.

The difficult problem is to compute the river discharge at any city arising from the rainfall on the watershed above.

Certain formulas have been proposed by which the river discharge may be computed. For instance, Mr. W. E. Fuller's formula, (Proc. Am. Soc. Civil Eng., Vol. 39, P. 1012) is

$$Q=CA^{0.8}$$

where Q is the average yearly flood, in cubic feet per second; C is the coefficient which is constant for the river at the point of observation; A is the catchment area of river in square miles.

Mr. Fuller remarks that the largest flood occurring in one hundred years will be 2.6 times the average yearly flood. This subject is now under lively discussion by engineers and other formulas are proposed, but all of these must depend upon the measurements of river discharge, which are lacking for conditions in Indiana.

The only certain method is to actually measure, by well known methods and tried instruments, the discharge of our rivers through a long term of years. Many States have done this in co-operation with the United States Geological Survey. Then the engineer will know the number of cubic feet per second of river-discharge for which flood protection works must be designed.

But we have made so little progress in scientific study of our streams that we are seriously handicapped in studies for flood protection.

Certainly one important effort that the State of Indiana must exert in the future is to provide for these streams gagings through a co-operative agreement with the United States Geological Survey, which has trained men and the instrumental equipment to perform this work efficiently.

These stream gagings would, however, require a long term of years for their completion.

Meanwhile many of our cities are in increasing danger from floods. In some cities the situation is acute and the people can not wait for a complete determination of scientific data before planning flood protection works.

For immediate purposes and in the absence of full information, the following method of solving the problem will be found useful and reasonably satisfactory.

Briefly, the method consists in finding the river discharge at selected points, the rainfall in the valleys above these points during the flood conditions of March, 1913, the general slope of the drainage area, and then to apply these measurements to watersheds of like character.

Diagram 10 shows our best information of river discharge in March, 1913. The number of cubic feet per second flowing from a square mile of watershed is shown in dashed line. These all had different slopes of watershed. In full line the measurements have been adjusted to a standard rainfall of seven inches, and to a standard average slope of watershed of 2 feet per mile.

The full line may be used with a reasonable degree of certainty to predict river discharge for the White River and the Wabash River watersheds in Indiana, after making allowance for the expected rain fall and the slope of the watershed.

For example, the area of the White River watershed above Indianapolis is 1680 square miles, for which area Diagram 10 provides a discharge of 39.5 cubic feet per second per square mile, (that is for a rainfall of seven inches and a standard slope of the drainage area of two feet per mile). But the expected rainfall for 1680 square miles is (Diagram 7) 10.35 inches. The fall from the rim of the watershed to Indianapolis is 450 feet in a length of 83.5 miles, and therefore the average slope of the bed of the drainage area is 5.40 feet per mile on an average.*

To find what river discharge Indianapolis may reasonably expect to pass through its flood protection works, we must increase the rate of discharge of 39.5 cubic feet per second per square mile, above mentioned, in proportion to the probable rainfall and also increase it as the fourth root of the slope. Our computation is then as follows:

$$39.5\times\frac{10.35\times}{7}\sqrt[4]{\frac{5.40}{2}}\times 1680=125{,}580 \text{ cubic feet per second.}$$

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*The slope of the river channel is less than the slope of the drainage area. For the White River above Indianapolis the average channel slope is 3.41 feet per mile.

DIAGRAM No. [illegible]

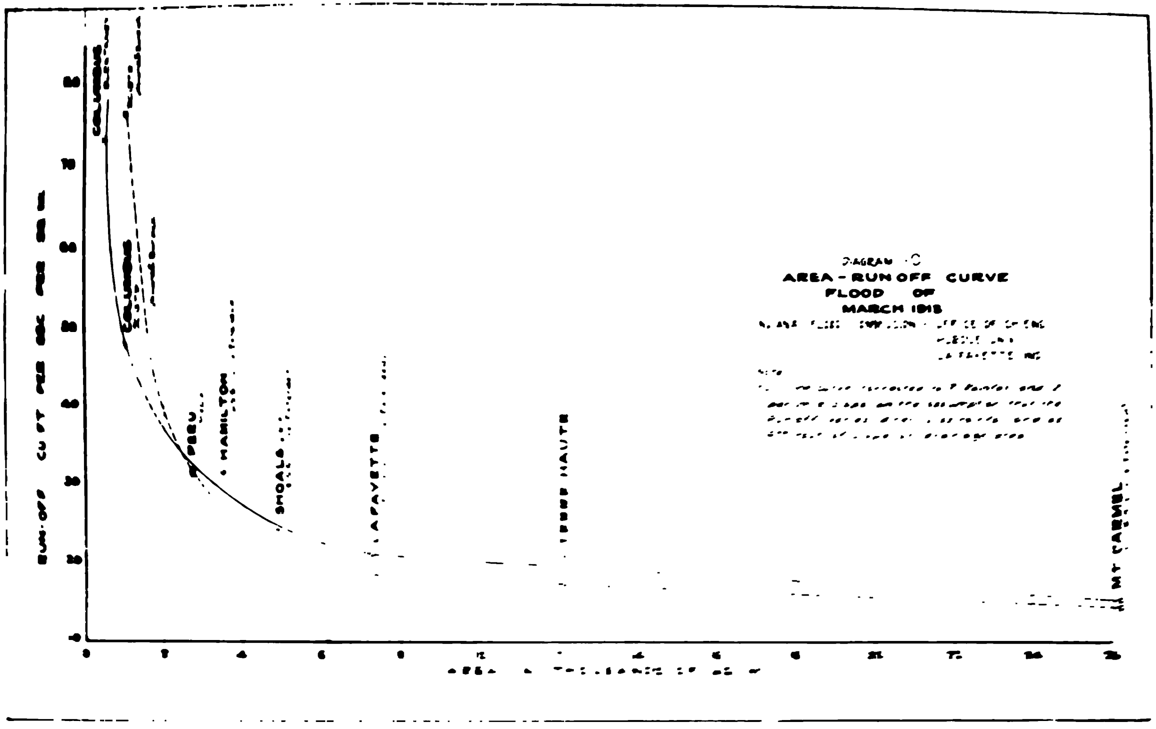


DIAGRAM [illegible]

AREA - RUN OFF CURVE
FLOOD OF
MARCH 1913

[illegible]

NOTE [illegible]

OPENINGS REQUIRED TO CARRY RIVER DISCHARGE.

The civil engineer is able to calculate the size of channel and the length of bridge opening to carry the river discharge. He must take into account local conditions, including the slope of the river bed, the alignment of the channel, whether straight or crooked, and the character of the material in the river bed. A steep slope with rock river-bed will permit a small channel where high velocities will not interfere with navigation.

It is impracticable to draw general rules to fit these local conditions in advance. As a rough estimate it may be stated that the velocities in improved river channels should not exceed six feet per second average velocity, and through bridge openings should not exceed eight feet per second.

For instance in the case of Indianapolis, there is indicated on this basis an area of channel of $\frac{125,580}{6} = 20,930$ square feet, and openings through bridges of 15,700 square feet. In this case the local conditions of the streams should be studied to see if such velocities can be obtained under the hydraulic characteristics of the channel.

The Indiana Flood commission is making a special study of bridge openings in this state, and is collecting statistics showing the bridge openings in our important streams and noting whether or not they were damaged in the flood of March, 1913. This study will not only serve to determine the measure of protection of these structures, against floods, but will serve as a basis for rules to determine the proper size of bridge openings in the future.

NEED OF SURVEYS.

We are also handicapped in studying floods in Indiana by the lack of topographic surveys, which show the contour of the surface of the State. These maps are not only useful and necessary for studying flood prevention, but serve a variety of other purposes as follows:

1. As preliminary maps for planning extensive irrigation and drainage projects, showing areas of catchment for water supply, sites for reservoirs, routes of canals, etc.
2. For laying out highways, electric roads, railroads, aqueducts, and sewerage systems, thus saving the cost of preliminary surveys.
3. In improving rivers and smaller waterways.
4. In determining and classifying water resources, both surface and underground.
5. In determining routes, mileage, location of road-building material, and topography in country traversed by public highways.
6. In classifying lands and in plotting the distribution and nature of the soils.
7. As base maps for the plotting of information relating to the geology and mineral resources of the country.

The State of Ohio has completed 87% of its survey, while Indiana has only 9% completed. See Map No. 4.

Certainly the State should enter upon this survey at an early day. It is estimated that by an appropriation of $50,000.00 annually for five years, this survey could be completed, under a co-operative agreement by which the United States Geological Survey would meet the remaining half of the cost.

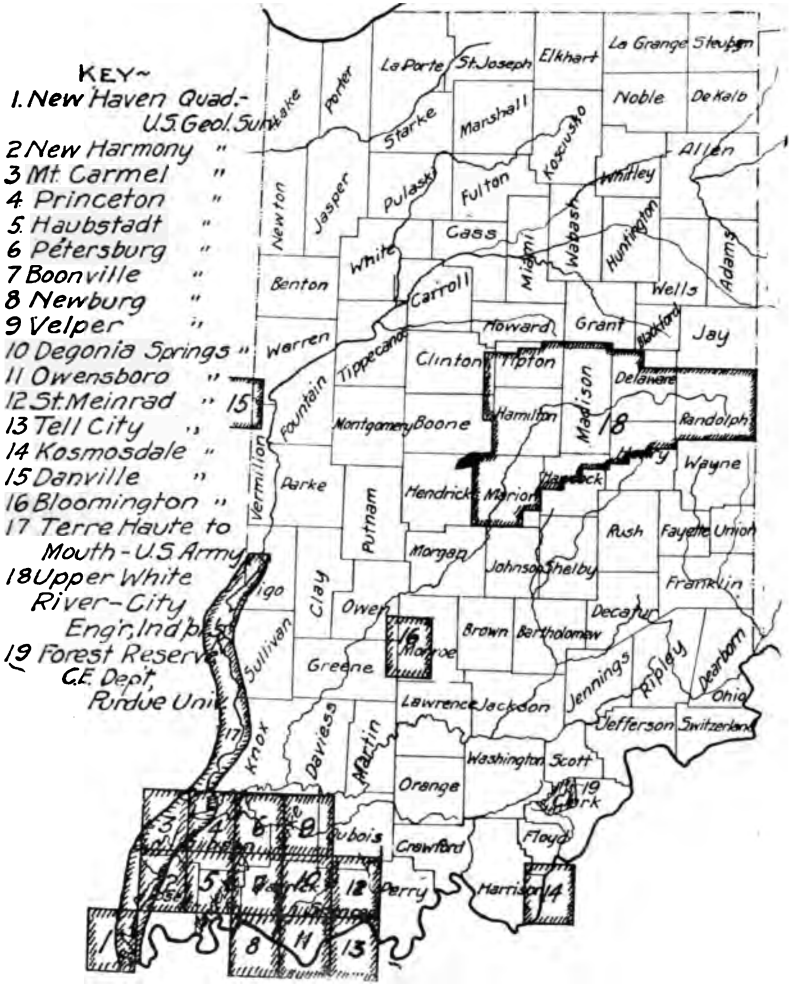
METHODS OF FLOOD PREVENTION AND PROTECTION.

In what ways may the flood waters be checked? Or if these flood waters reach our cities, how may the protection works be constructed?

Reservoir Control.

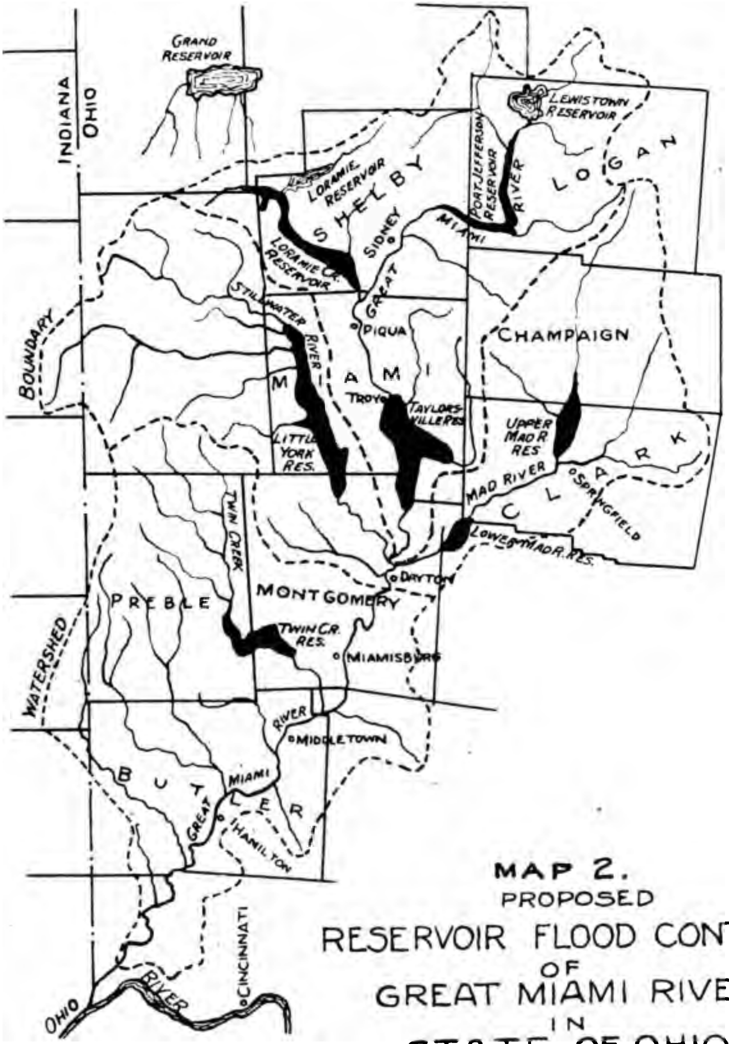
While we can not prevent the rain from falling, we can in some cases detain it in reservoirs placed in the upper watersheds for a time, and let it out gradually in the channels and thus diminish flood heights below.

MAP No. 4.



AREAS SURVEYED IN STATE OF INDIANA.

MAP No. 2



MAP 2.
PROPOSED
RESERVOIR FLOOD CONTROL
OF
GREAT MIAMI RIVER
IN
STATE OF OHIO
SCALE
0 5 10 20

AUTHORITY~
ENG. RECORD
MAR. 28, 1914

INDIANA FLOOD COMMISSION
OFFICE OF CHIEF ENG'R.
PURDUE UNIVERSITY
LAFAYETTE, IND.

Such flood control by detention reservoirs has been used in Europe and is planned for the Great Miami River in Ohio. See Map 2.

The flood waters in the upper Miami are to be collected in impeding or detention reservoirs, shown in black locations on the map. These are not storage reservoirs, but

DIAGRAM No. 11.

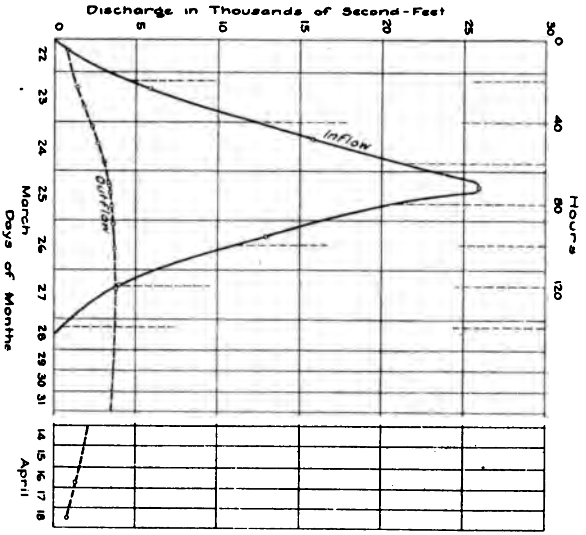


DIAGRAM NO. 11.

EFFECT OF PROPOSED UPPER MAD RIVER RESERVOIR ON STORM OF MARCH, 1913.

Run-off 90% of Rainfall

From Eng Rec Vol. 69 No 13

INDIANA FLOOD COMMISSION
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LA FAYETTE, IND

they discharge automatically through channels always open, through the bottom of the dams. These channels are so proportioned that the greatest flow through them will not exceed the carrying capacity of the stream below. See Diagram 11. In the case of the Miami Valley, it was found that the entire valley including both cities and farm lands could be protected from flood damage at a cost of $17,000,000.00 by this method of impounding reservoirs. On the other hand, the cost of the separate works that were planned by a number of individual cities along the river, for city protection alone, using the ordinary methods of levees and channel improvements, amounted to over $100,000,000.00.

It is interesting to know that this system was accurately planned by the use of the topographical maps of the State of Ohio.

We do not know if such reservoir control can be obtained in Indiana, because we have not the surveys nor the stream gagings to use in the studies of our streams. The use of such reservoirs depends upon the question of fact, that is, the existence of favorable topography and natural reservoirs.

The land back of the dams constructed for these detention reservoirs is not thrown out of cultivation, and would only be covered with water during very severe floods.

These impounding or detaining reservoirs should not be confused with storage reservoirs. The latter store the water and use it for power purposes and water supply. Incidentally a series of such storage reservoirs may mitigate the effects of floods.

Levees and Channel Improvements.

The common solution of flood protection to cities is to widen the channels and improve them by taking out obstructions, and to build levees along the banks.

Planning levees and channel improvements is the work of the civil engineer. The size and slope of the channel must be properly related to the flood waters, the proper type and height of levees designed, and consideration must be given to the effect of these on sewer systems, and grades of streets. Often bridges must be redesigned.

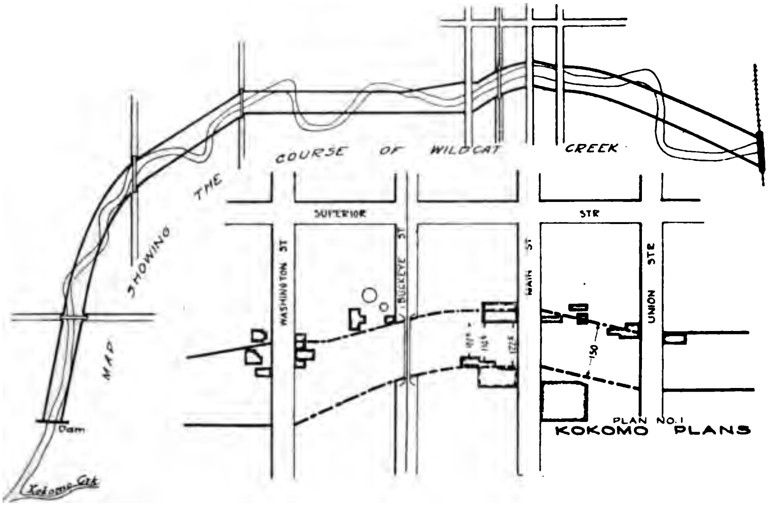
Sometimes the best solution will be found in a cutoff channel. Certain typical plans for levees and channel improvements are shown in Plans 1 to 3.

The following cities in Indiana have been active in flood protection studies and reports: Indianapolis, Fort Wayne, Peru, Kokomo, and Lawrenceburg.

In planning such flood protection works, difficult problems are found in the re-construction of old bridges and in the existence of factory buildings where flood water should be allowed to pass.

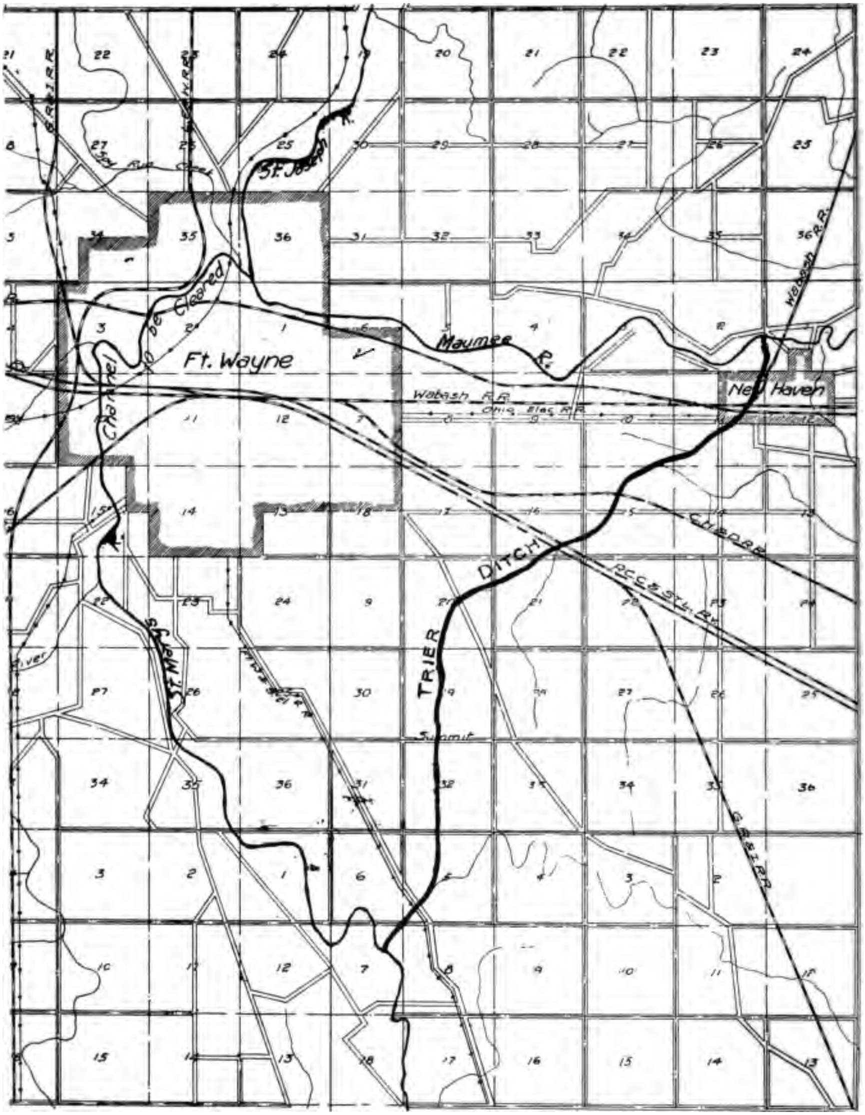
Indeed a large problem presents itself in deciding the best public policy with respect to the proper use of the flood plain of our rivers, as distinct from the channel. In modern cities it seems unreasonable to give up to the river its complete flood plain, as in the state of nature. However, the river will certainly demand a portion of it and this portion should be laid out in parks or devoted to other uses in which an occasional flood will not result in a loss of life or a great loss of property.

PLAN No. 1.



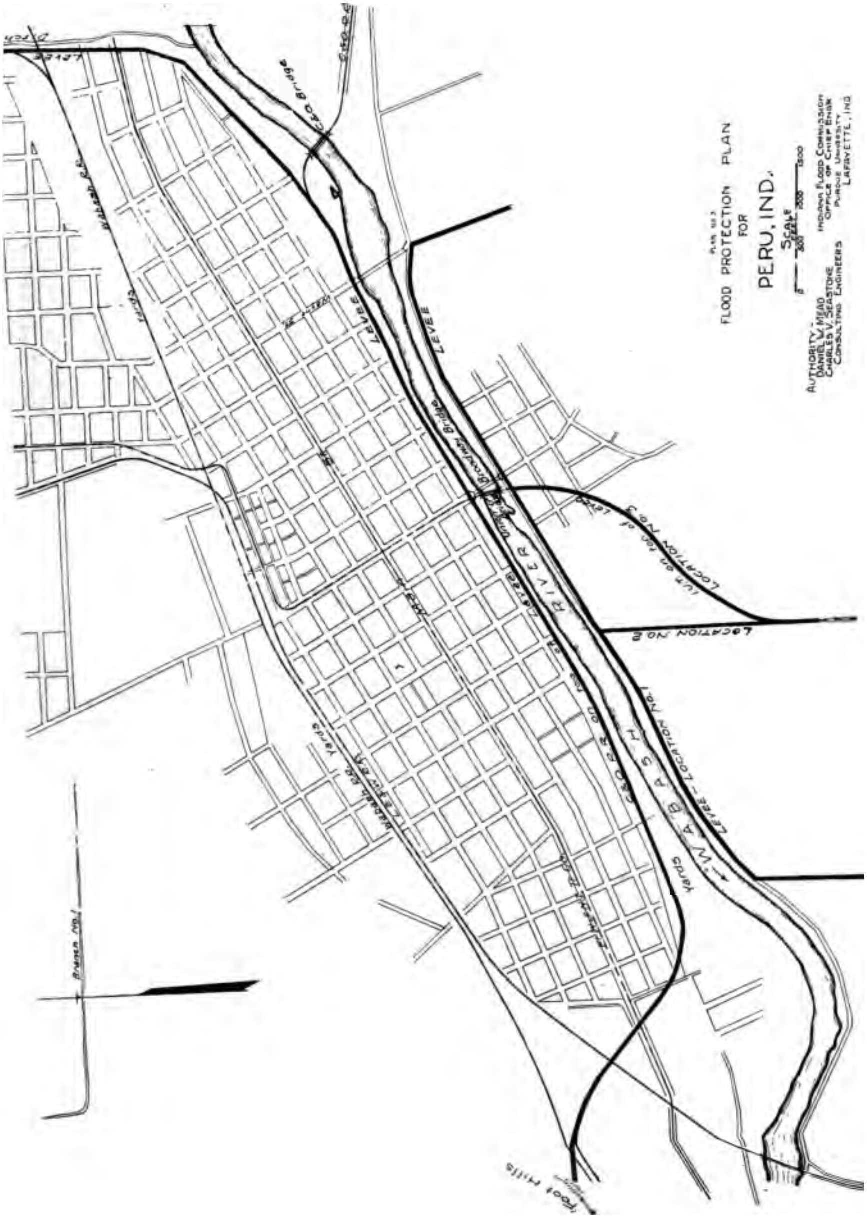
KOKOMO PLANS OF STREAM CHANGES.

PLAN No. 2.



FLOOD PROTECTION PLAN FOR FT. WAYNE, IND.
Authority: Report by A. W. Grosvenor.

PLAN No. 3.


PLAN NO 3
FLOOD PROTECTION PLAN
FOR
PERU, IND.
SCALE
FEET
0 500 1000 1500
AUTHORITY:
DANIEL W. MEAD
CHARLES V. SEASTONE
CONSULTING ENGINEERS
INDIANA FLOOD COMMISSION
OFFICE OF CHIEF ENGR
PURDUE UNIVERSITY
LAFAYETTE, IND
LEVEE
LEVEE
Bridge
Broadway Bridge
WABASH RIVER
LOCATION NO 2
LOCATION NO 3
LEVEE - LOCATION NO. 1
Wabash R.R.
Yards
Yards
Foot Hills

At this point a remark must be made as to the depressing effects upon the character and industry of people who are continually liable to flood damage.

Other Methods of Mitigating Flood Damage.

Forestation may mitigate ordinary floods, but it does not appear that this is a practical solution in Indiana. Special methods of plowing, such as contour plowing, have been advocated. Mr. Freeman Thorpe of Hubert, Minnesota, advocates contour plowing. His idea is to so shape the upper surface of the ground, that it will be subdivided into relatively small units, entirely surrounded by ridges. In fact he would terrace, on a small scale, the side hill slopes. The elevations are so gradual that they do not interfere with the ordinary crop arrangement in handling. Practically each one of these terraced areas is a detaining reservoir of very small size.

FLOOD PROTECTION AND RIVER CONTROL.

As a matter of fact, flood protection is related to other problems, namely those of water supply, soil erosion, navigation, and water power. To diminish floods is to diminish soil erosion, which is one of the very serious problems affecting agriculture and navigation.

ANCIENT WORKS FOR CONTROL OF RIVERS.*

Water has been the element with which man has had to battle from earliest times. The problem of floods and flood control is not a new problem. From earliest times people have known the fearful consequences of water that has gotten beyond control, where from slave it has become master.

Those who witnessed the power of unrestrained water in March, 1913, know what it means, and has meant back to the dawn of civilization. Here is an element that when harnessed is gentle and gives friendly support, in so many ways, and when out of bounds becomes something terrible and sinister. Its destructive manifestation is not a quick flash of anger like that of a wind storm, but a slow gathering together, a remorseless and resistless rise of power.

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*Abstracted from paper by Sir William Willcocks, Engineering Record, Vol. 69, page 471, April 25, 1914.

The earliest records of civilization go back to the valleys of the Euphrates and the Nile and in both cases the ancient rulers of these regions counted it the very highest honor to have served the people by effectively controlling the floods and harnessing the waters to the use of the people.

In the valley of the Euphrates the success of agriculture depended then, as now, on the irrigation and the control of the river.

Our present methods of flood control were known to them. Indeed the more complete our knowledge of ancient people, the more our respect for them as engineers becomes. Ancient Babylonians controlled the Euphrates both by a system of levees along the banks to protect the agricultural lands in the low-lying districts, and they also drew off the flood waters from the upper reaches into escape basins which were depressions in the Arabian Desert, hundreds of square miles in area and twenty-five feet deep. The Tigris river was not controlled upstream and the dikes downstream frequently burst.

In Persia also, rivers discharging the volume of the Wabash at Lafayette were controlled by masonry dams.

Again the ancient rulers of Egypt built dikes along the Nile and drew off the flood waters into a wide and deep depression from which these waters were returned to the river after the flood for use in irrigation.

Indeed history abounds with a record of not only the use of flood protection works, but the cutting of them in times of warfare.

These ancient works were all thorough. They were effective and desirable, and presented an example of the benefits to be derived from associated action.

LOCAL VS. VALLEY INTERESTS.

A city may build improved channels and levees that sluice the water through the city and pile it up on communities down stream. Conversely, the county commissioners or railroad corporations may build a bridge that acts as a dam and backs the water up on persons up stream.

Again the levee system of a city, to be effective, must extend beyond the city, and will demand the widening of the railroad and county bridges.

As in the Miami Valley it might be found that the best interests of all parties will be served by the examination of the upper river for detaining reservoir sites.

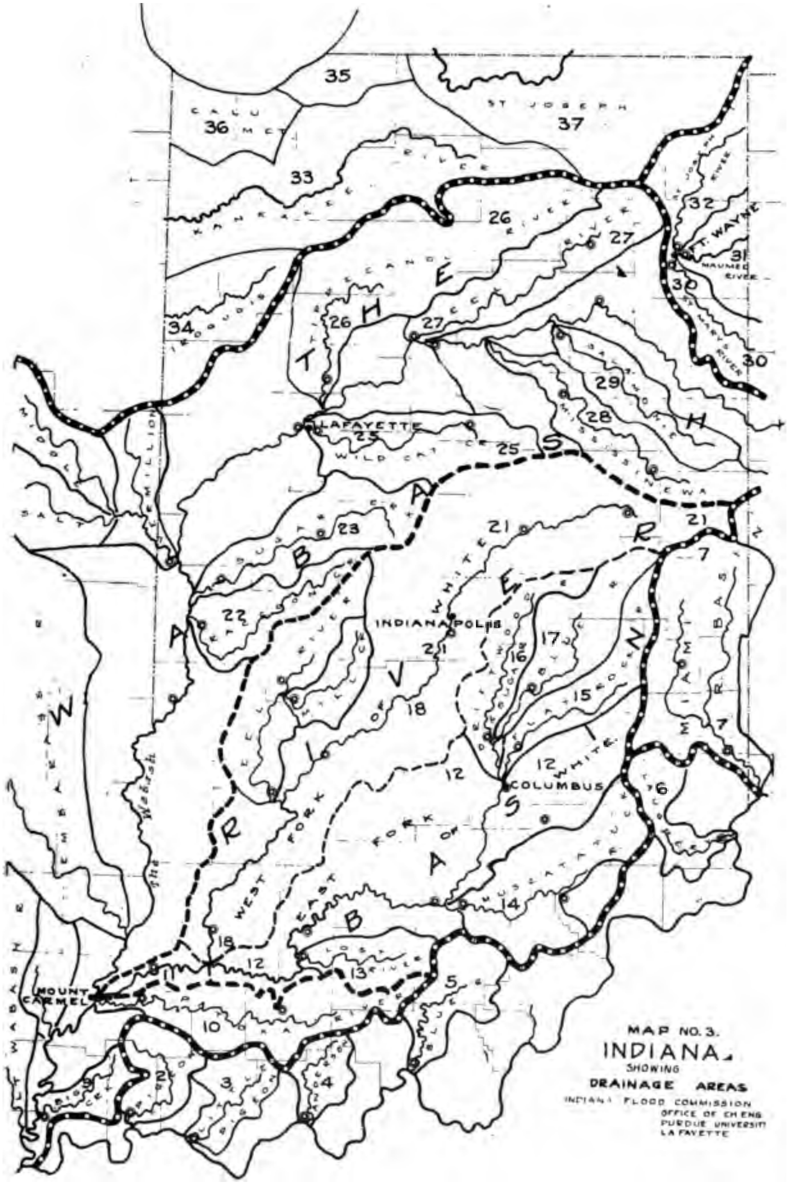
Indeed it is clear at the outset that flood protection problems must be viewed from a standpoint not of one locality, but of the entire watershed, both with respect to planning flood protection works, and providing for the cost of building them. The drainage areas of main streams of Indiana are shown in Map No. 3.

In Indiana the cities in the northern Wabash Valley have organized a Northern Wabash Valley Flood protective association, comprising the cities of Lafayette, Logansport, Peru, Wabash, Huntington and Fort Wayne. Fort Wayne has been included because its problems are of the same nature as those of the other cities. Indeed there is a physical possibility that Fort Wayne may protect itself by sending the waters of the St. Mary's River over a low divide into the Wabash River.

INTERESTS OF THE STATE IN FLOOD PROTECTION.

The entire facts presented thus far would naturally suggest to the reader that the state has a direct interest and can exercise a helpful co-ordination in flood protection problems of our people. It is the state that must study the problem from a wide point of view and on the underlying data such as rainfall and topography.

MAP No. 3.


MAP NO. 3.
INDIANA
SHOWING
DRAINAGE AREAS
INDIANA FLOOD COMMISSION
OFFICE OF CH ENG
PURDUE UNIVERSITY
LA FAYETTE
35
CALU MET
36
33
ST JOSEPH
37
KANKAKEE RIVER
26
27
32
31
30
ST. JOSEPH RIVER
FT. WAYNE
MAUMEE RIVER
ST. MARYS RIVER
34
IROQUOIS
TIPPECANOE
THE
29
28
MISSISSINEWA
SALAMONIE
H
LAFAYETTE
25
WILD CAT CR.
S
VERMILLION
SALT
23
22
A
B
21
R
7
WHITE
E
INDIANAPOLIS
N
WHITEWATER
17
16
15
18
V
I
EEL RIVER
MILL CR.
WEST FORK OF
EAST FORK OF
12
WHITE
COLUMBUS
S
6
W
EMBARRAS
The Wabash
R
WEST
FORK
FORK
OF
A
14
MUSCATATUCK
B
13
LOST RIVER
19
11
12
5
MOUNT CARMEL
PATOKA RIVER
10
BLUE
2
3
4
BIG CREEK
PIGEON
LITTLE PIGEON
ANDERSON
WABASH

It is the state that must act as intermediary between the cities, counties, and corporations whose combined action is necessary in the construction of flood protection works. It is the state which must provide legislation arranging such co-operation and providing proper legal methods by which districts may be defined and money raised for building flood protection works.

It is the state which must see that these flood protection works, such as levees and reservoirs, are properly maintained, that they may be a real protection instead of a future menace.

Finally it is the state that is interested in the welfare of the whole people, and itself suffers when lives are lost, business and transportation are interrupted and sickness ensues, and entire communities are disturbed and set back by the constantly recurring floods.

Furthermore, it is the state which must represent the people in the final solution of these problems, through combined action of other states and the federal government. Watersheds are not political divisions, but are natural divisions and problems of flood protection have to do with watersheds.

LEGISLATION.

A problem of immediate great importance in Indiana is to secure flood protection works, that is, to finance the works and to properly maintain and regulate them. There are no laws in the State of Indiana to provide for construction of flood protection works, and no existing officers or commissions into whose hands the supervision of the construction of such works, or their approval and regulation, could be placed.

There is no control provided by the state over the acts of communities in constructing flood protection works that might seriously endanger communities further down the stream. There is no law providing for the co-operation of several parties to the construction of flood protection works, namely, the city, county, and suburban districts. Such a law is needed because a flood protection plan generally involves building levees along the banks of the river, the widening of county and railroad bridges, and extending the levees beyond the limits of the city.

For instance, the city of Peru was especially damaged by the flood of March, 1913. Seventeen lives were lost and the total damage was over $2,000,000. Immediately after the flood the citizens employed a competent engineer who planned flood protection works, consisting of a series of levees extending from the foothills above to those below town, along the river banks, and providing for the opening up of the county and railroad bridges.

The city of Peru can not now obtain the much needed protection unless legislation provides some means for the co-operative action, as between the city, county, railroad and outlying districts.

The state should also assume the supervision of our streams to prevent encroachments and channel obstructions that unreasonably obstruct the free flow of flood waters.

LEGISLATION IN OTHER STATES AND COUNTRIES.*

The French nation was eminent early in the history of water control and flood protection. A system of flood legislation originated in France, and upon it has been based the practice in other European countries. In France flood districts are established and administered by officers called prefects. They supervise the organization and administration of all water-control districts. The costs of the flood protection works in these districts are taxed on property in proportion to the benefits derived, largely through the establishment of zones of relative benefit.

Generally in Europe the construction and operation of flood protection works are administered by administrative officials, rather than through the courts.

In New York state, a Conservation Commission appointed by the Governor considers flood protection, and prepares, with the aid of a technical staff, flood protection plans. Before the works are constructed the final approval of the project rests with the legislature.

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*Prepared by E. W. Shirk, Chairman Indiana Flood Commission.

In Minnesota there is an ex-officio Commission consisting of the Governor and two other state officers, to which an engineering staff is attached.

The state of Ohio has made the greatest progress in flood legislation. After the flood of March, 1913, the legislature passed a Conservancy act under which petitioners in any locality may petition the courts of common pleas for the establishment of a conservancy district. The court determines the petition and may, after evidence, establish the limits of the district, appoint directors to build the works, and establish an assessment roll, assessing benefits and damages within this district.

These systems are described in greater detail below.

OHIO CONSERVANCY LAW.

Under petition filed in the office of the clerk of the court of common pleas and signed either by 500 or more freeholders or a majority of the free holders, or by the owners of more than half of the property in either acreage or value within the limits of the territory proposed to be organized into a conservancy district, the judge of this court, or if the conservancy district lies within more than one judicial district, the judges of such judicial districts sitting together set a date for the hearing of the petition, notice of which is published by the clerk of the court. If this hearing develops the necessity for the formation of a conservancy district, then the court decrees its incorporation and within thirty days appoints a board of directors of three resident freeholders within the district who shall administer the affairs of the district, employ agents and prepare a so-called official plan which is then given a hearing in the event of objections within thirty days of its filing. These directors upon final approval of the official plan have the right of eminent domain over all property in the Conservancy District, including public utilities, and may condemn for the use of the district according to the procedure provided by law. This board shall also have the right to establish and maintain, stream gauges, rain gauges, flood warning service, etc., and may co-operate with the United States government or other agencies or states to carry out the official plan. The court organizing the district appoints three appraisers, nominated by the board of directors, whose duty it is to appraise all benefits and damages accruing to all lands within that district. No appeal under the act is permitted to interrupt or delay the prosecution of any work under the act. The directors may issue bonds or borrow money or pay with warrants against the district, levy assessments and contract for all works provided under the official plan. Their acts are limited by the official plan and they are under no supervision. The difficulty which has so far developed in Ohio, with this conservancy act has been in securing the agreement of the various judges sitting together, whose approval has been necessary for the establishment of conservancy districts.

NEW YORK CONSERVATION LAW.

The New York law establishing a Conservation commission is almost the opposite of the Ohio law, the sole object of which is to provide for protection against floods. The New York Conservation commission has authority over hydraulic development, river improvements, drainage, water supply, forests, public parks, etc.; this very wide field of activity involves in addition to the three commissioners, the employment of three deputy commissioners and a variety of secretaries, engineers, etc. So far as flood prevention goes, it may proceed with the establishment of a district on petition of a public corporation, a private individual or on its own motion after an examination into the necessity for the proposed improvement, and after holding an advertised public hearing in regard to it. But the letting of contracts under any plan of improvement and the authorizing of bonds, which are issued and signed by the Commission, must await the approval of the plan by the legislature of the state. The Commission is given the right to condemn property where necessary for the execution of the plan. The Commisson determines the necessity for it, and upon receiving the legislature's approval, finances and erects all works.

FRENCH WATER CONTROL LAWS.

In France protection against floods is affected either by:

(1) Voluntary associations under the law of June 21, 1865.

(2) Compulsory syndicates organized by the administration of the district or the government, by authority of the law of September 16, 1807.

(3) Or by the government itself, under the law of May 28, 1858. When the works are especially for the protection of cities, projects are worked out, in the case of voluntary associations, by the engineers of a commission appointed by such association and must be approved by the prefect, and shall also be submitted for the approval of the minister of public works. Voluntary associations cannot enforce membership or condemn, and are in fact restricted to minor works where the members are few and their interests are altogether in common.

When the project is carried out under the law of 1807, by a compulsory syndicate, the taxes are apportioned on the basis of the following:

(1) The fixation of the boundaries of protection.

(2) Classification of the properties included within these boundaries into different zones, called "zones of danger" according as they are more or less exposed to overflow.

(3) Establishment of these same boundaries.

This system, combined with the classification into zones gives the measure of the benefit received from the works by

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